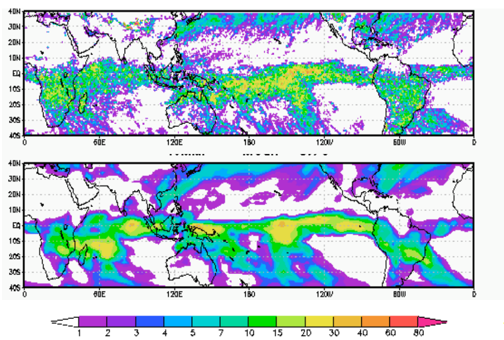
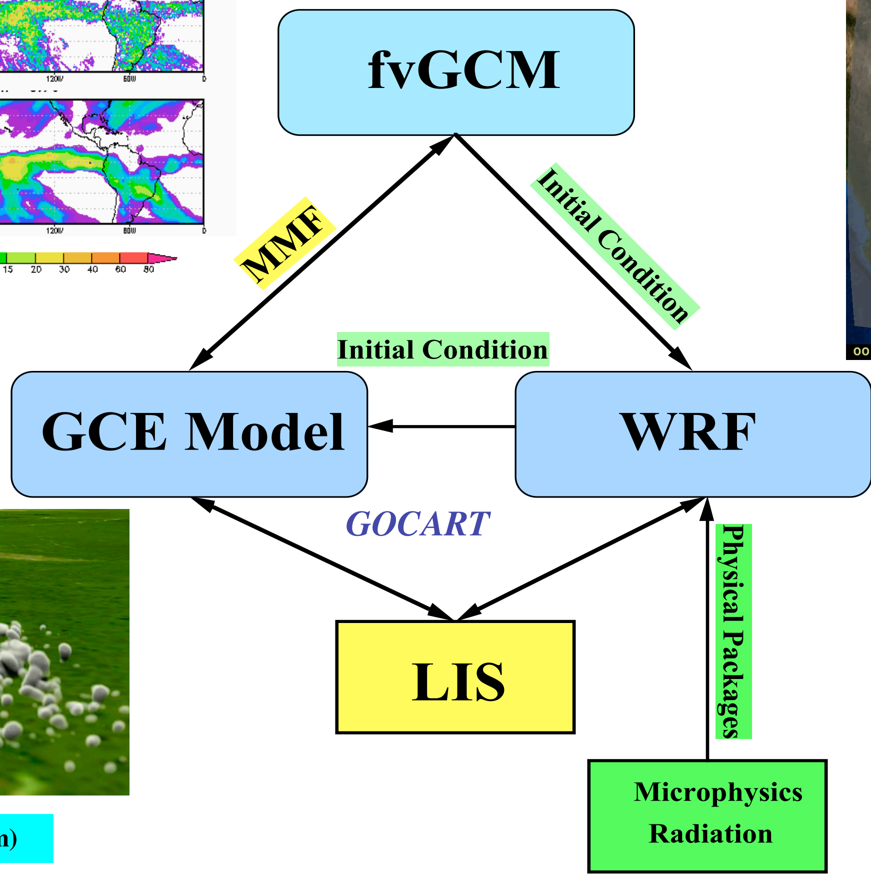
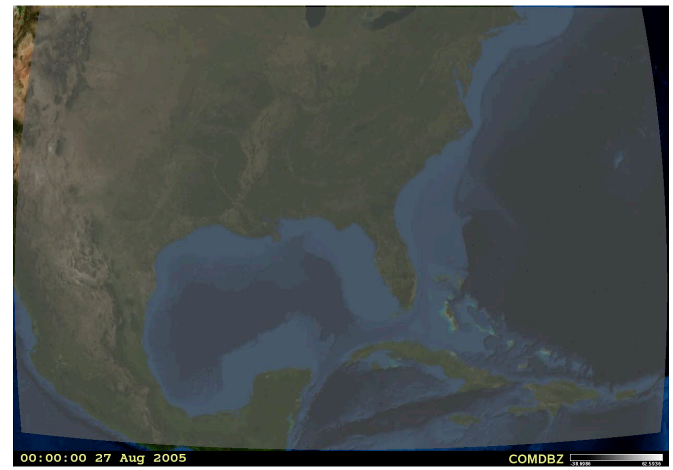
Multi-Scale Modeling System with Unified Physics

TRMM Jan/99



MMF



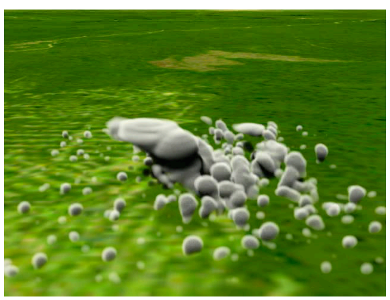


WRF- *Hurricane Katrina*

(1.67 km, 2 min)

Observation

Satellite Data
Field Campaigns
Re-analyses (MERRA)



GCE - LBA (250 m)

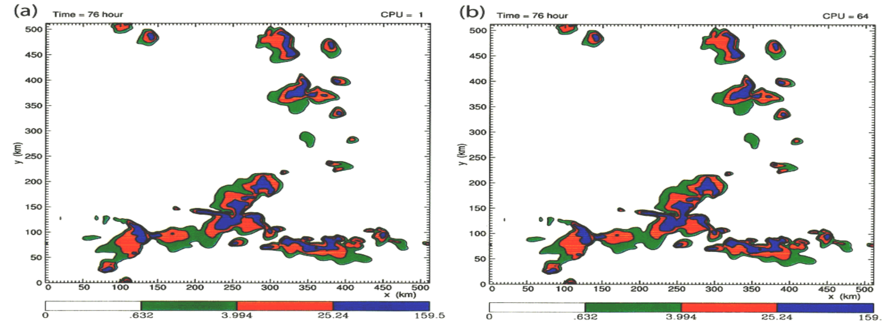
MMF: Multi-Scale Modeling Framework
LIS: Land Information System
GCE: Goddard Cumulus Ensemble Model
WRF: Weather Research Forecast

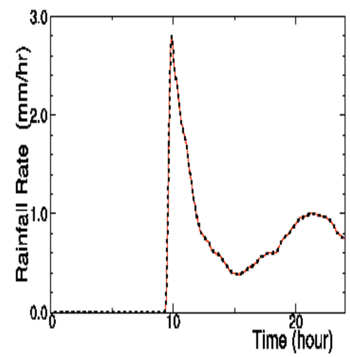
Microphysical Package (5 options)
& Long/Shortwave Radiative Transfer
(including cloud-radiation interaction)

Tao, W.-K., D. Anderson, J. Chern, J. Estin, A. Hou, P. Houser, R. Kakar, S. Lang, W. Lau, C. Peters-Lidard, X. Li, T. Matsui, M. Rienecker, M. R. Schoeberl B.-W. Shen, J.-J. Shi, and X. Zeng, 2009: Goddard Multi-Scale Modeling Systems with Unified Physics, *Annales Geophysics*, **27**, 3055-3064.

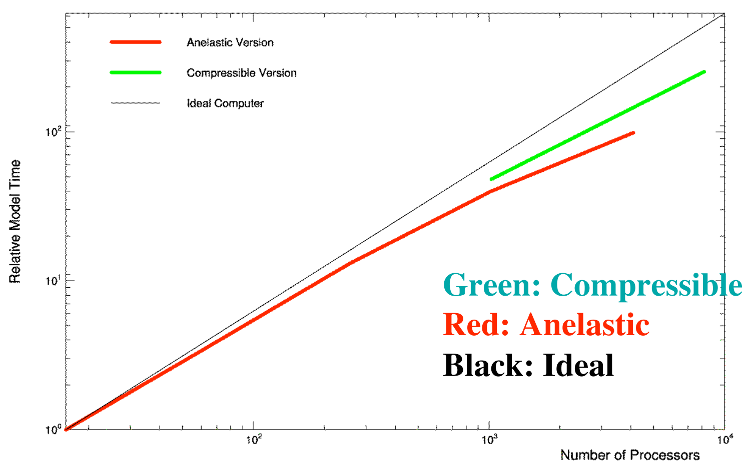
GCE Model's characteristics and computational performance

Parameters/ Processes	GCE Model
Dynamics	Non-hydrostatic: Anelastic or Compressible 2D (Slab- and Axis-symmetric) and 3D
Vertical Coordinate	Z (height)
Microphysics	2-Class Water & 3-Class Ice 2-Moment 2-Class Water & 2-Moment 5-Class Ice Spectral-Bin Microphysics
Numerical Methods	Positive Definite Advection for Scalar Variables; 4th-Order for Dynamic Variables
Initialization	Initial Conditions with Forcing from Observations/Large-Scale Model Re-analyses (MERRA)
FDDA	Nudging
Radiation	k-Distribution and Four-Stream Discrete-Ordinate Scattering (8 bands) Explicit Cloud-Radiation Interaction
Sub-Grid Diffusion	TKE (1.5 order)
Surface Energy Budget	Force-Restore Method 7-Layer Soil Model (PLACE) Land Information System (LIS) TOGA COARE Flux Module
Parallelization	OPEN-MP and MPI





Almost no differences in instantaneous and accumulated surface rainfall between 1 CPU and 512 CPUs



Model configuration: 2048 x 2048 x 41
1 km grid spacing and 6 s time step

8192 CPUs: 12 h integration, 4 h wall clock

Climatologically, 40-dBZ penetrations above 10 km are rare even over land (Zipser et al. 2006; Liu et al. 2008).

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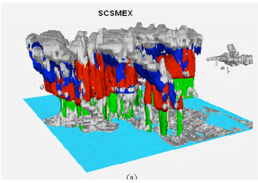
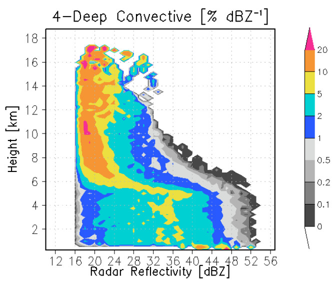
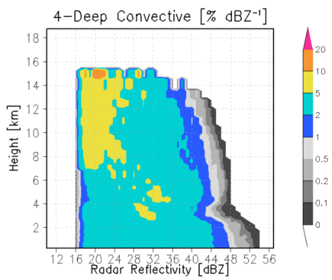
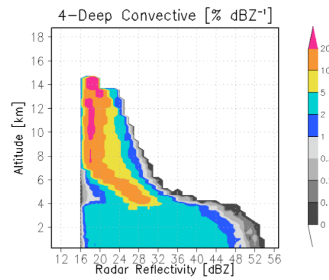


S. China Sea Monsoon (TRMM Data)

Reduce 40dBZ at high altitude







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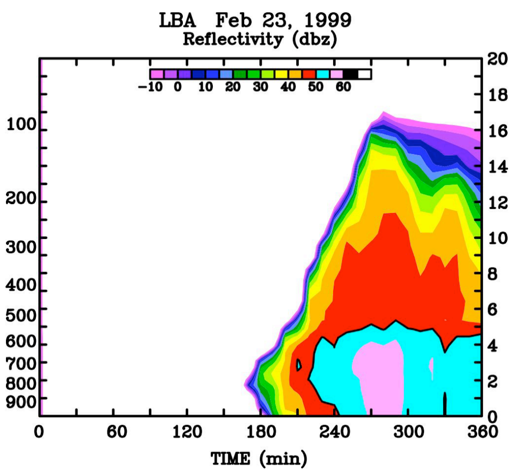
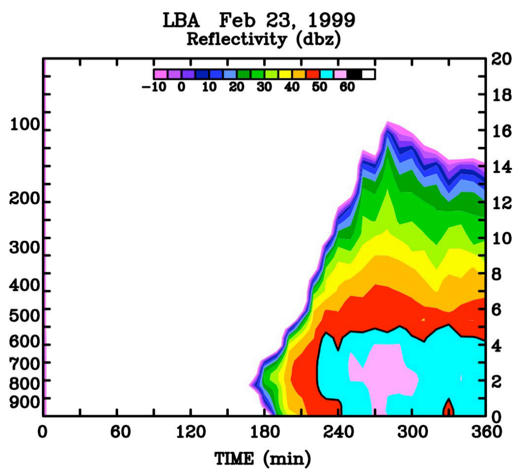
Use Spectral bin microphysics to develop Temperature dependent drop size distribution (TeDD)

LBA (Ground based radar)





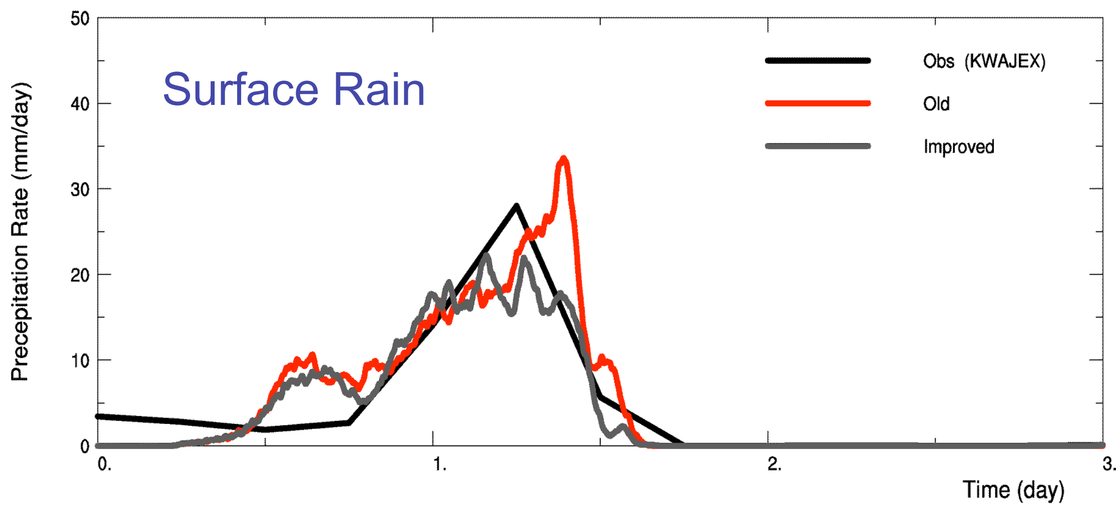
High resolution simulation of 23 Feb 1999 TRMM LBA case

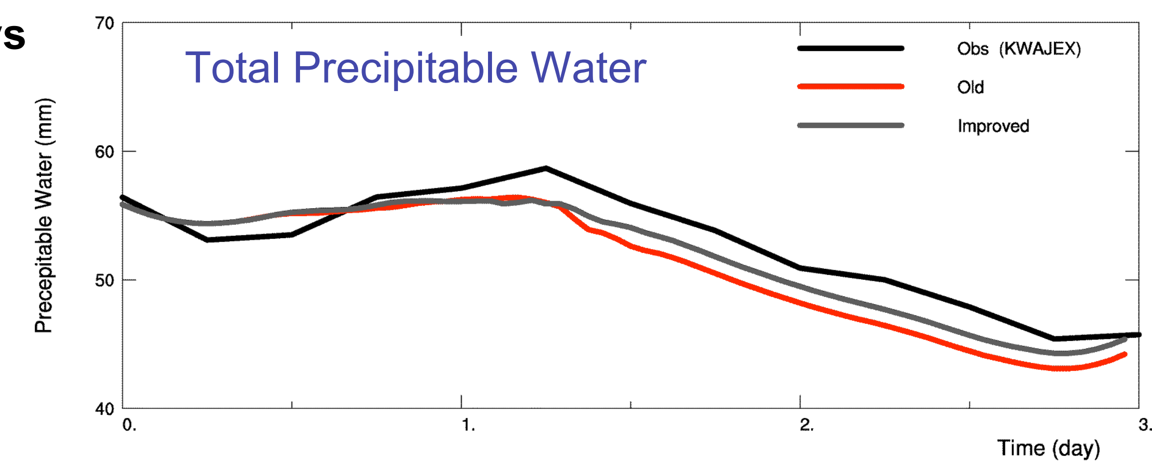
Riming, contact nucleation and immersion freezing and several

KWAJEX 3-day simulations start at 0600 UTC 11 August 1999

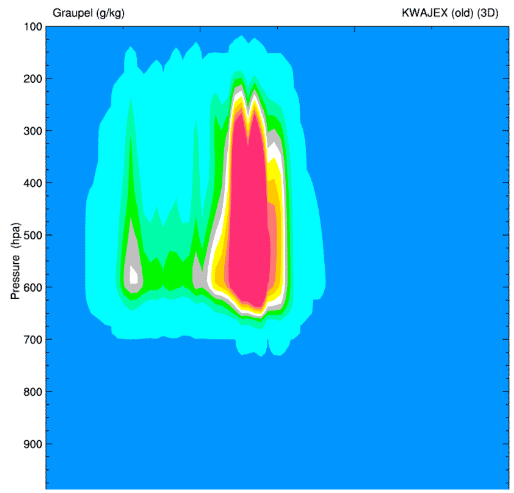
256 x 256 grid points, 2 km
41 vertical layers
6 s time step

BLACK: Observed
RED: Original Microphysics
GRAY: Improved Microphys

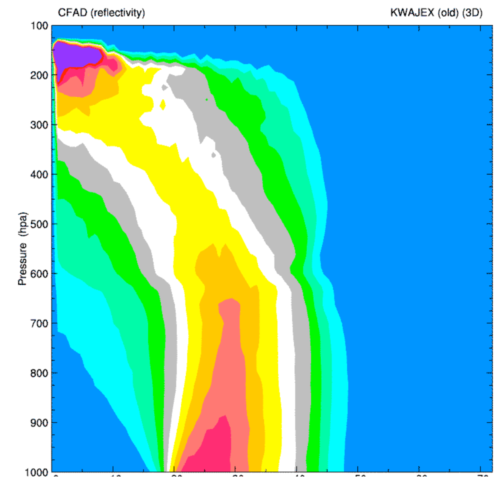




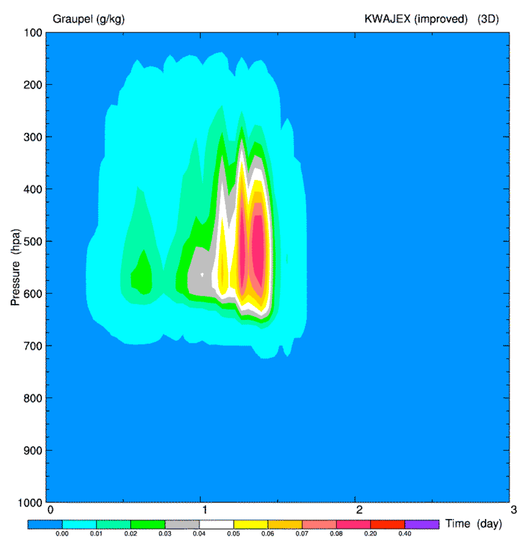
KWAJEX Simulated Graupel and CFAD (dBZ)



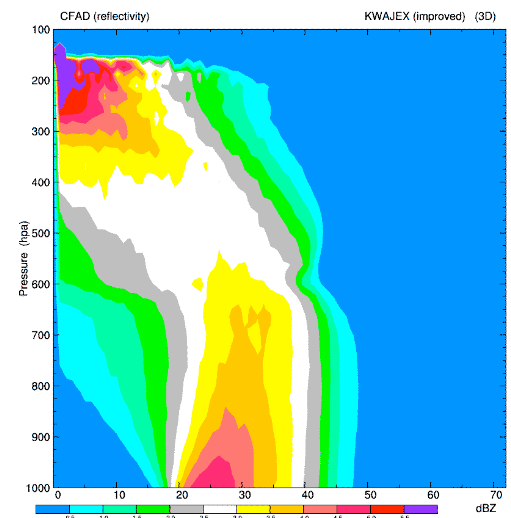
Original



Graupel



Improved



Adding number concentration of each cloud specie based on one-moment bulk scheme

Large-Scale Forcing imposed to CRM

Soong and Tao (1980)

(1) Horizontal and vertical advection for both T and Q
(meaningful for comparison with observation - used by CRMs to improve CPs)

$$[\frac{\partial\overline{\theta}}{\partial t}]_{LF} = -\overline{V} \bullet \nabla\overline{\theta} - \overline{w}\frac{\partial\overline{\theta}}{\partial z} \qquad [\frac{\partial\overline{q}}{\partial t}]_{LF} = -\overline{V} \bullet \nabla\overline{q} - \overline{w}\frac{\partial\overline{q}}{\partial z}$$

(2) Horizontal advection and large scale vertical velocity
(physically realistic - used by CRMs to study quasi- equilibrium states)

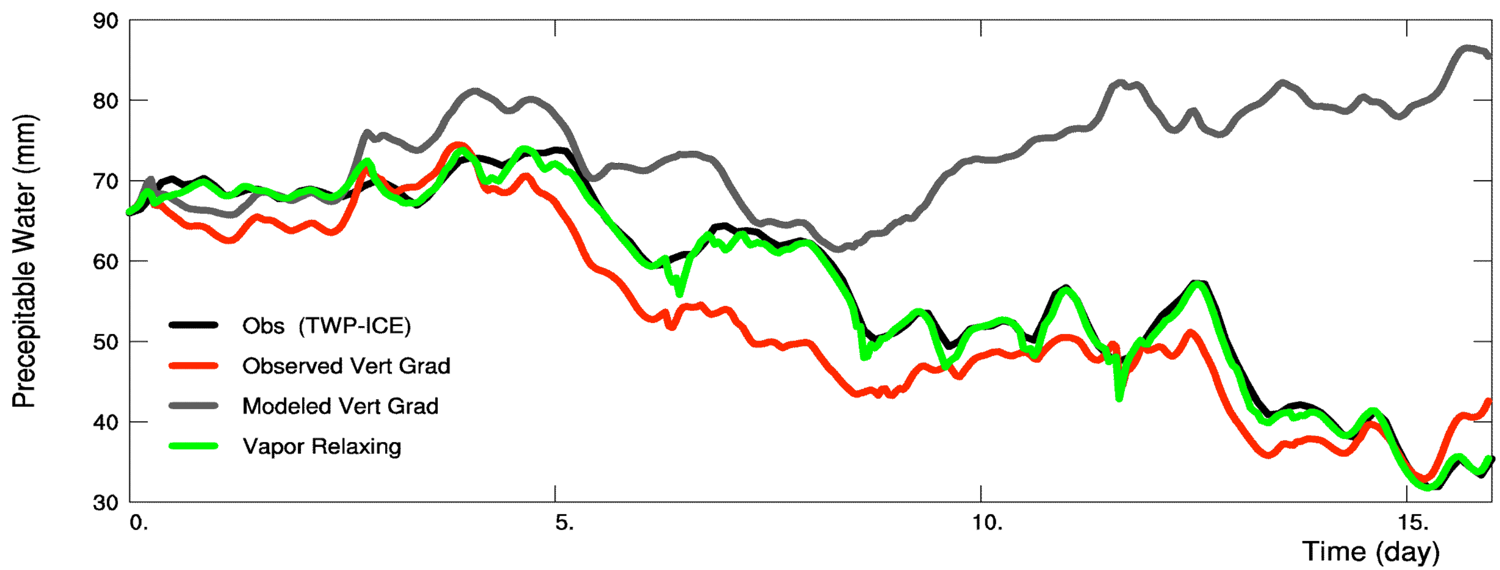
$$[\frac{\partial\overline{\theta}}{\partial t}]_{LF} = -\overline{V} \bullet \nabla\overline{\theta} - \overline{w}(\frac{\partial\overline{\theta}}{\partial z})_{CRM} \qquad [\frac{\partial\overline{q}}{\partial t}]_{LF} = -\overline{V} \bullet \nabla\overline{q} - \overline{w}(\frac{\partial\overline{q}}{\partial z})_{CRM}$$

Wu et al. (1998)

(3) Vapor relaxation (nudging Q)

$$[\frac{\partial\overline{\theta}}{\partial t}]_{LF} = -\overline{V} \bullet \nabla\overline{\theta} - \overline{w}\frac{\partial\overline{\theta}}{\partial z} \qquad [\frac{\partial\overline{q}}{\partial t}]_{LF} = -\frac{\overline{q}_{CRM} - \overline{q}}{\tau}$$

TWP-ICE (16 day) Simulations starts at 1500 UTC 19 January 2006

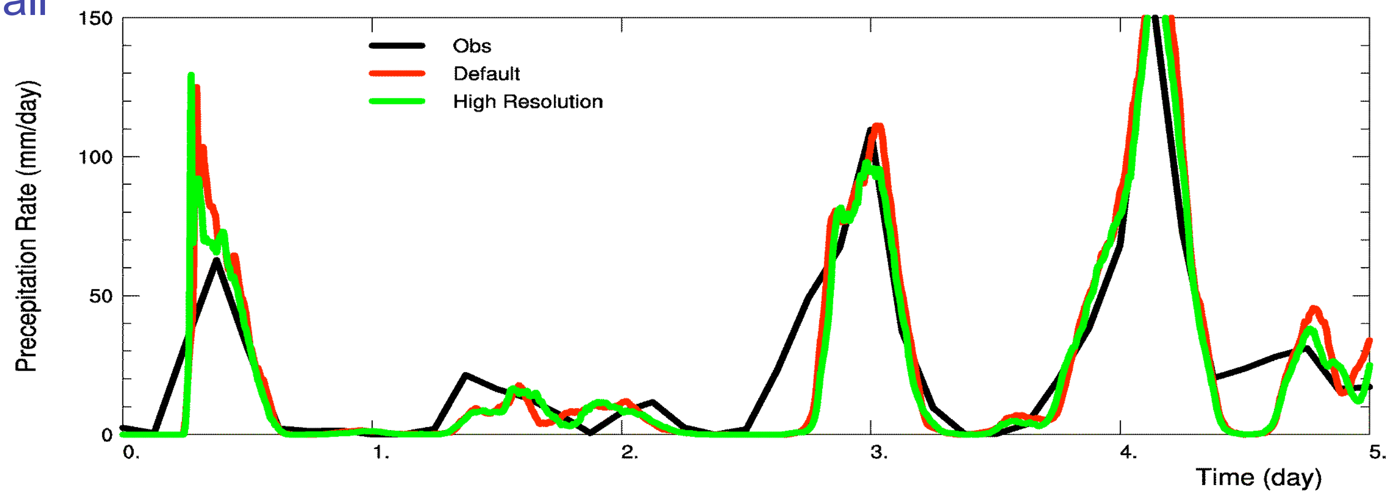


256 x 256 grid points, 2 km
41 vertical layers
6 s time step

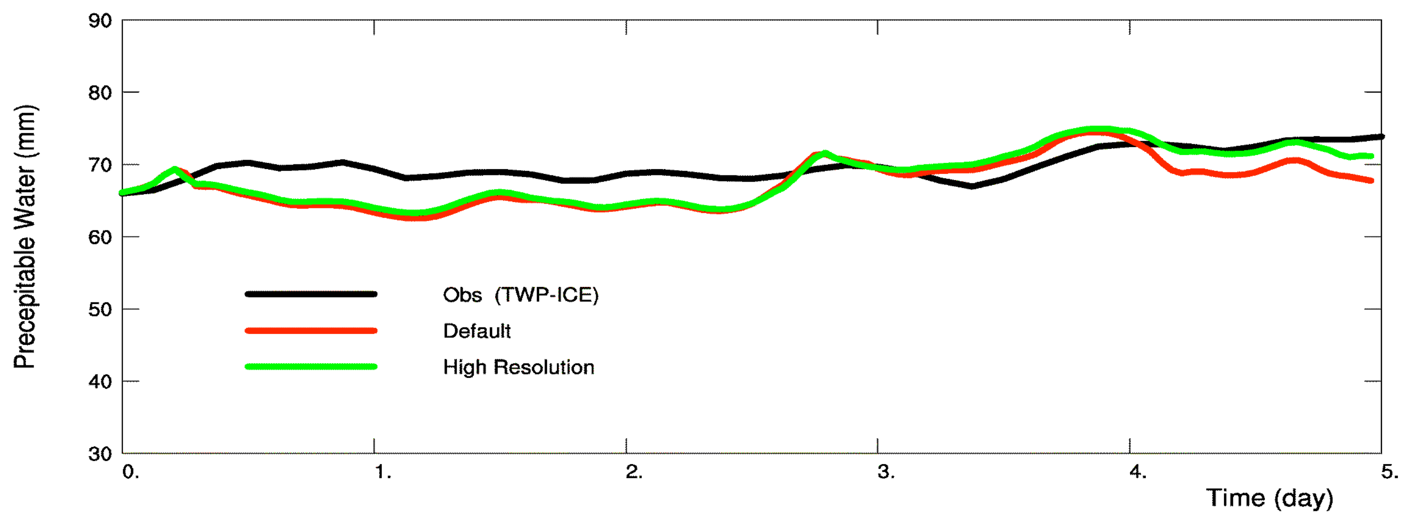
TOGA-COARE: 2nd (modeled vertical gradient) and 3rd method (vapor relaxing) are in better agreement with observation than the 1st method

TWP-ICE Simulations with Different Vertical Resolution

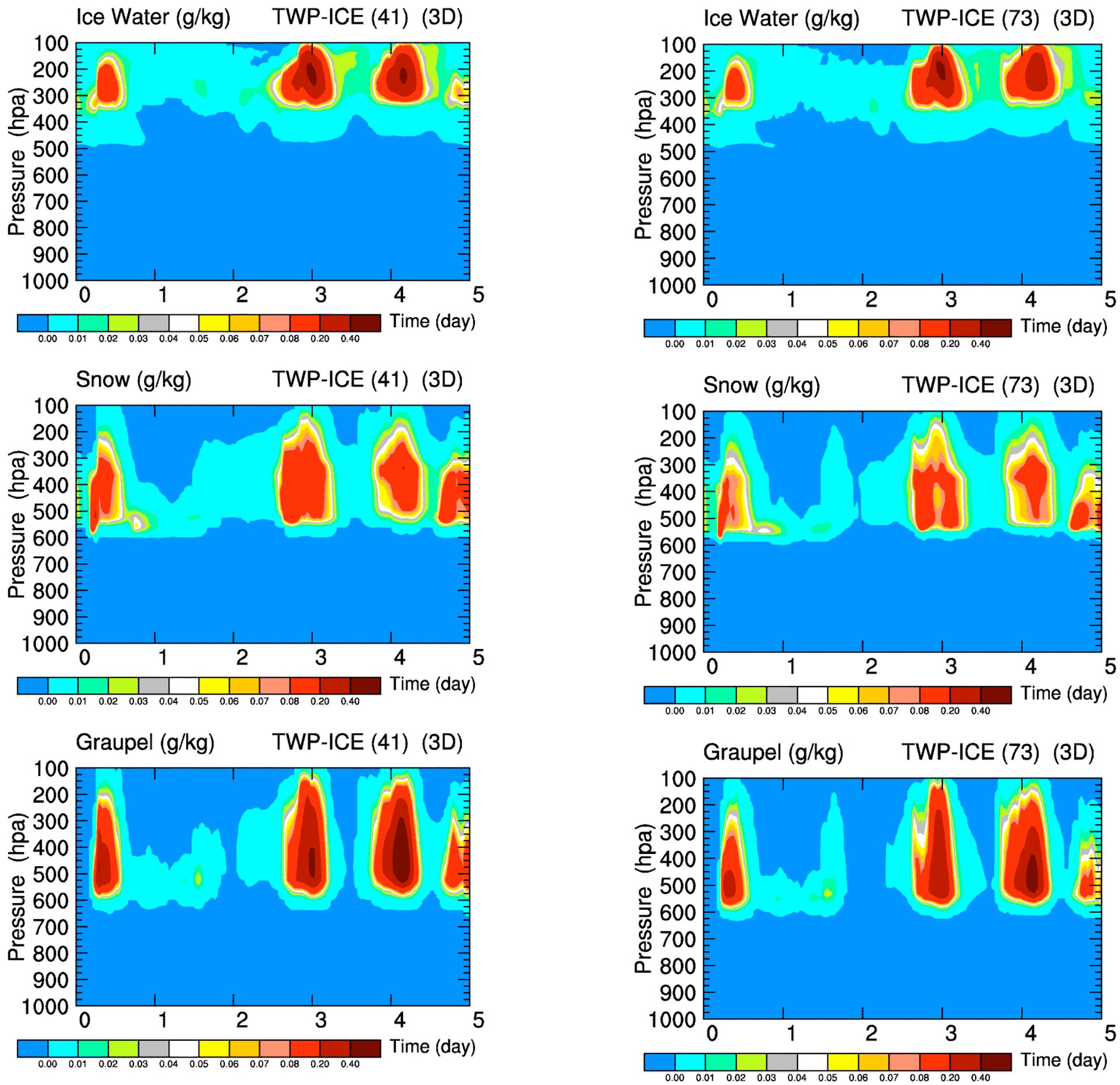
Rainfall



Precipitable water



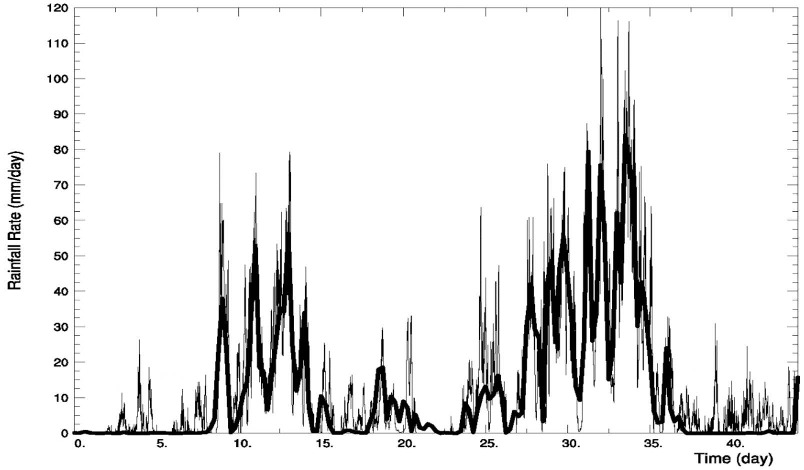
TWP-ICE Simulations with Different Vertical Resolution

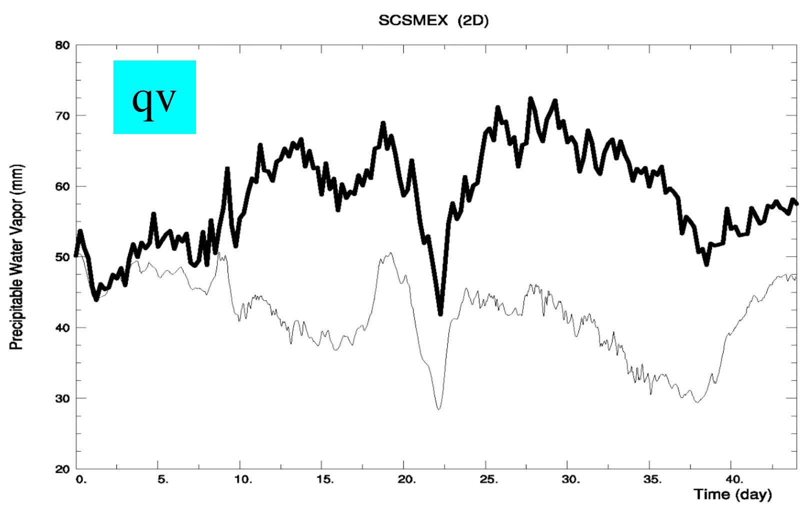


GCE model long-term (>40 days) simulated rainfall and water vapor (qv) for SCSMEX (S. China Sea 1998) case

Zeng, X., W.-K. Tao, S. Lang, A. Hou, M. Zhang, and J. Simpson, 2008: On the sensitivity of Atmospheric ensemble to cloud microphysics in long-term cloud-resolving model simulations. *J. Meteor. Soc. Japan*, Special Issue on high-resolution cloud model, **86**, No. 6, 839-856.

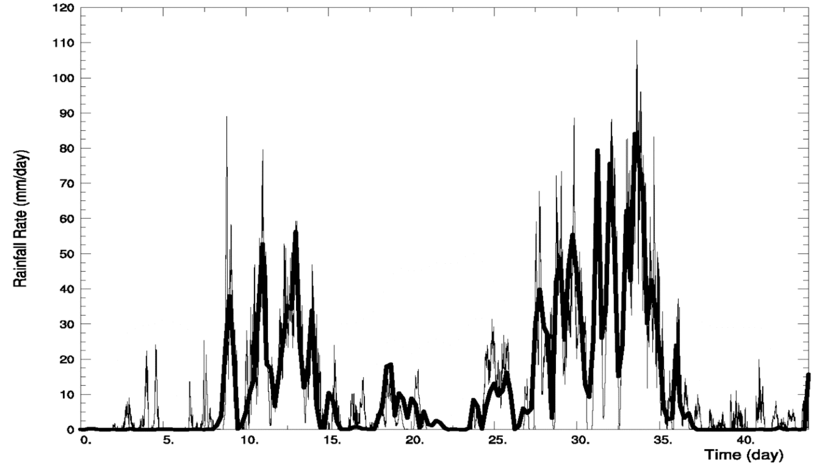
Time series of rainfall

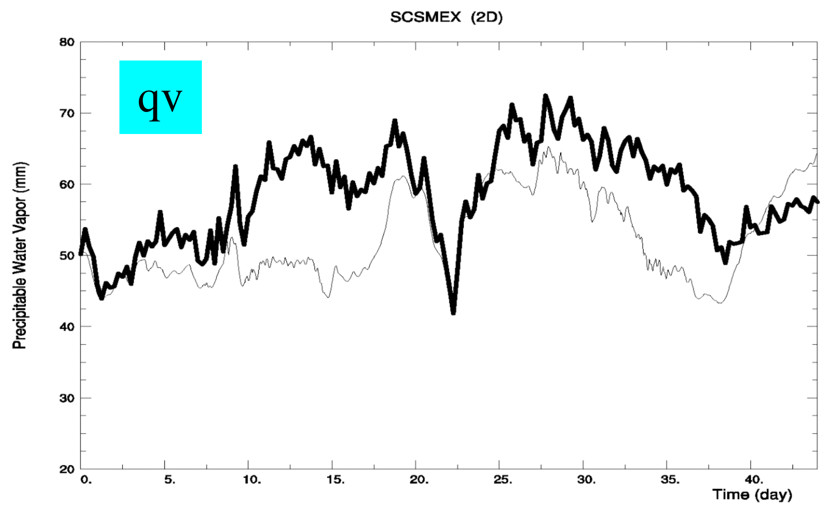




Original ice processes

Time series of rainfall





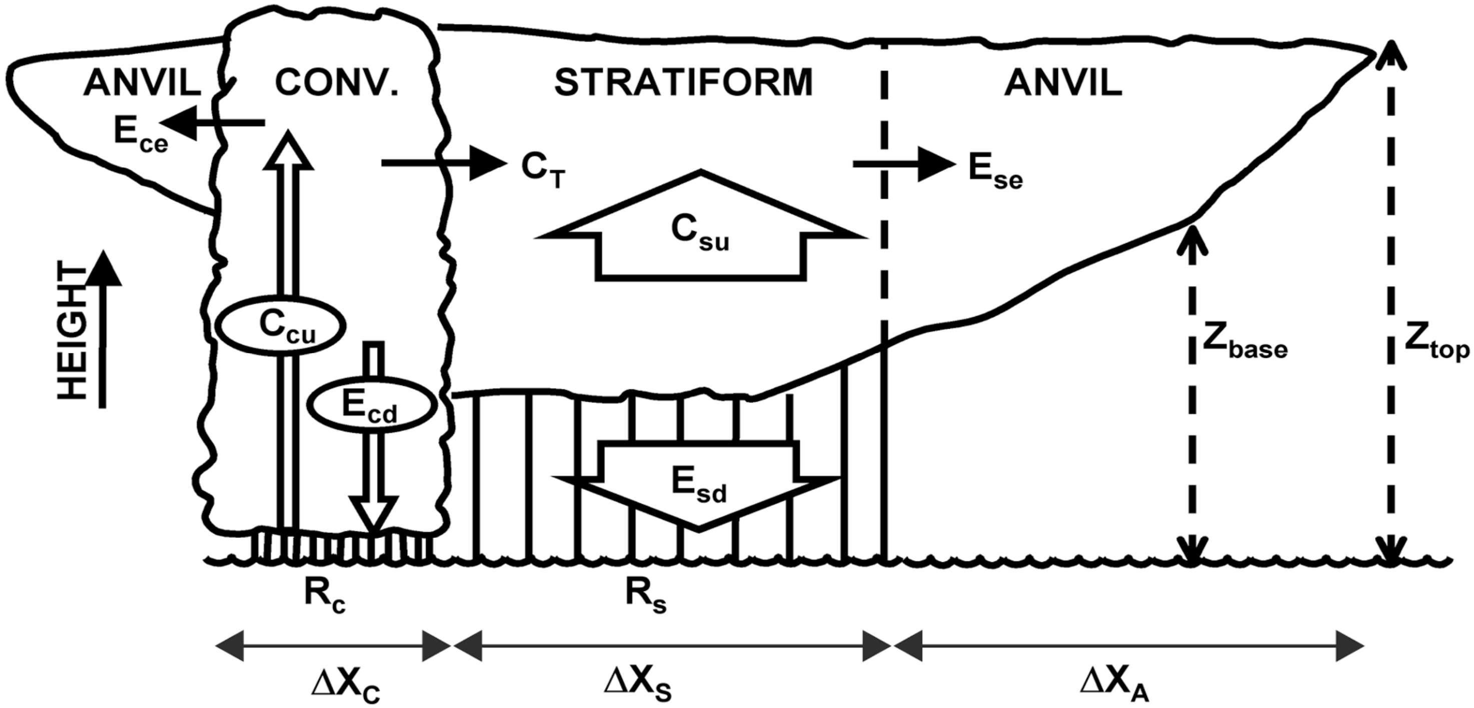
Improved ice processes

Use of ARM observations and numerical models to achieve physically consistent representation of radiative and latent heating profiles

Wei-Kuo Tao, Xiping Zeng (NASA GSFC)
Robert Houze, Jr., Jian Yuan (University of Washington)
Sally A. McFarlane (Pacific Northwest National Laboratory)

To use an improved (microphysics and cloud-radiation interactions, surface processes) high-resolution cloud-resolving model and ARM data to

- **Determine the water budget of an MCS**. The terms in the water budget relate to both the net latent heating (how much water is precipitated) and to the **anvil structure** (how much water goes into anvil). Relating latent heating and anvil production to the MCS water budget assures that the heating profiles are physically and dynamically consistent.
- Assess how **microphysical processes affect the structure of anvil clouds of MCSs**. Determine to what extent the anvil structure is determined by diffusional growth (deposition and sublimation) and by collection processes (riming and aggregation).
- Calculate the **profiles of both latent and radiative heating** associated with an MCS and its associated anvil cloud. As noted above these profiles will be physically consistent with the MCS dynamics.
- Represent convection in general circulation model (GCM) calculations. Specifically, the Goddard Multiscale Modeling Framework (Goddard/**MMF**), which combines the Goddard/CRM with a GCM will be used to determine the impact of the MCS anvils on the tropical general circulation.
- Generate a **database of internally consistent anvil structures and latent and radiative heating profiles for MCSs** in a wide variety of geographical locations and climatic regimes



Schematic vertical cross section of an idealized MCS with convective region (CONV.), associated stratiform precipitation region and non-precipitating cirrus-form anvil. Adapted from Houze et al. (1980). The horizontal dimensions of the convective, stratiform, and anvil regions are indicated by , and . The various terms in the schematic represent sources and sinks of condensate in the convective, stratiform, and anvil regions. These terms represent the amount of convective region condensation (C_{cu}) and the portions of the convective region condensation that are rained out (R_c), evaporated in the convective downdrafts (E_{cd}), detrained to an anvil (E_{ce}), and transported into the stratiform region (C_T). Condensate in the stratiform region includes C_T plus the amount of condensate generated by the stratiform updraft (C_{su}). Part of ($C_T + C_{su}$) is rained out (R_s), part is evaporated into the downdraft (E_{sd}), and part (E_{se}) is detrained to or left aloft in a thick anvil or ice cloud.

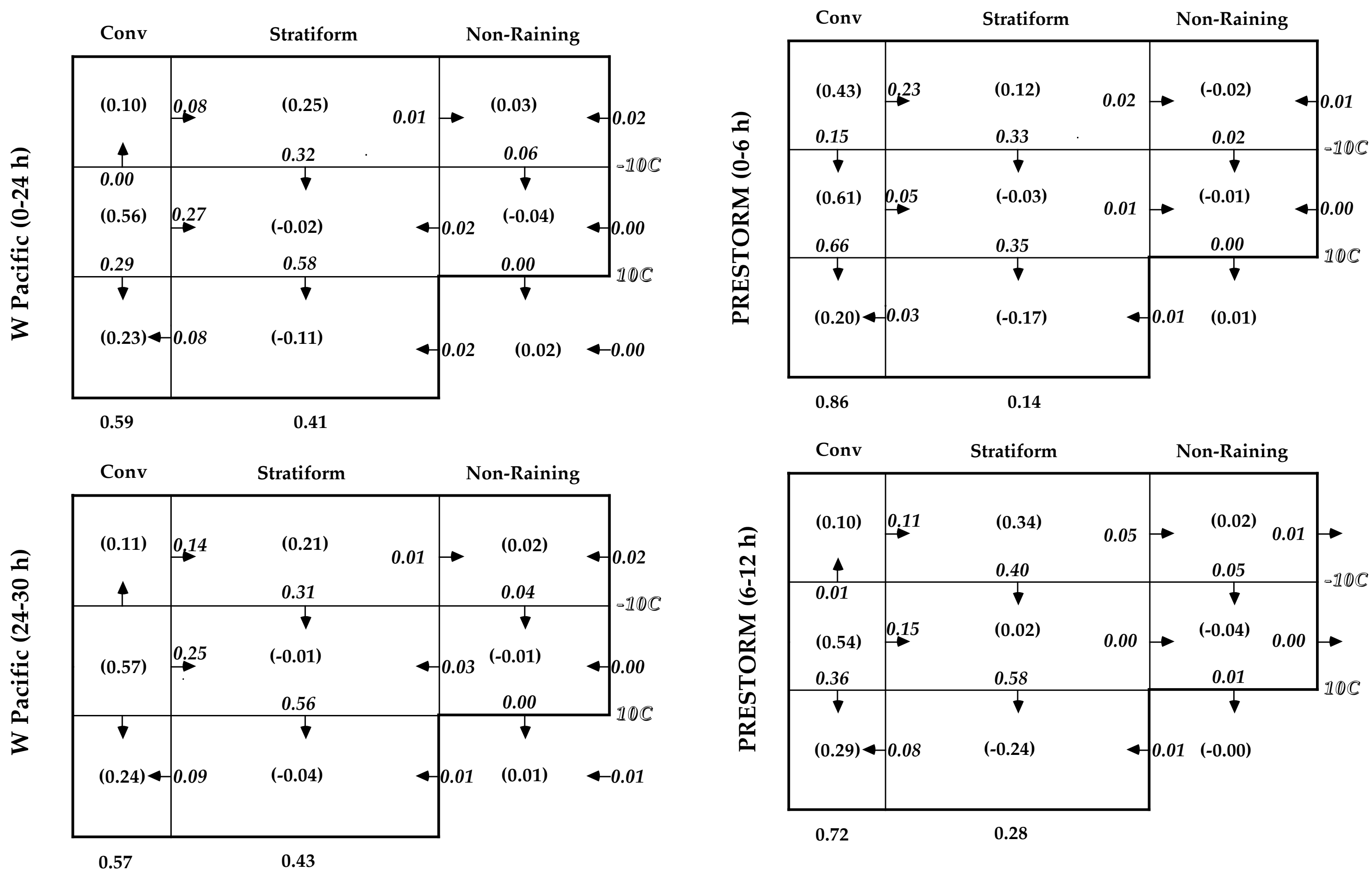


Fig. 5 Simulated cloud (condensate) water budgets for a West Pacific and a PRE-STORM convective system. Numbers with arrows indicate the amount of condensate transferred between various regions and layers while quantities in parentheses are the net condensation (condensation + deposition – evaporation - sublimation) generated through microphysical processes. The left two panels are for the West Pacific case but at different life times. The right two panels are for the PRE-STORM case. The convective and stratiform percentages are shown at the bottom of each panel. The units are normalized with the total rainfall amount. In thestratiform region beneath 10 C for the PRE-STORM mature stage (bottom right panel), downward transport (0.58) is the dominate process forstratiform rain (0.28), evaporation (-0.24) the dominate microphysical process, with modest horizontal transfer to the convective region (-.08) and from the non-surface raining region (0.01) (i.e., 0.28 = 0.58– 0.24 – 0.08 + 0.01). The -10 C to 10 C layer encompasses the mixed phase region for the PRESTORM case. These results suggest that the role of the convective region in the generation of anvil/cirrus and stratiform rainfall is very important.

Tao, W.-K., 2003: Goddard Cumulus Ensemble (GCE) model: Application for understanding precipitation processes, AMS Meteorological Monographs - Cloud Systems, Hurricanes and TRMM. 107-138.